5.0 APPROACH AND LANDING AIDS

5.1 Introduction

The purpose of this section is to examine approach and landing systems used today, and the relationship of these systems to the need for aircraft operations in low-visibility conditions.

This will be done by:

(1) Explaining the operation of the system as an approach and landing aid.

(2) Establishing the operational limits of the system and why these limits exist.

(3) Pointing out inherent difficulties in modifying the system to achieve low-visibility capability.

Aircraft landings may take place under two basic flight regulations; visual flight rules (VFR) when meteorological ceiling exceeds 1000 feet and instrument flight rules (IFR) when ceiling is below 1000 ft. The lower limits for IFR landings are established by Federal Regulations and based upon such factors as aircraft and ground equipment capabilities, runway lengths and lighting and surrounding terrain.

Table II-19 gives the meteorological definition and decision heights associated with categories of landing limits as well as the present-day authorization of various approach and landing aids.

TABLE II-19. PRESENT DAY AUTHORIZATION OF LANDING SYSTEMS AT LEVELING CATEGORY LIMITS

Definition				Federal Authorization			
Category	RVR (ft)	Met. Visibility	DH (ft)	ILS	VOR/ DME	GCA/ PAR	Automatic Landing Systems
I	2400	1/2 mi	200	Yes	No	Yes	Yes
IIA	1600	1 4 mi	150	Yes (few airports)	No	Yes (military only)	Yes
IIB	1200	3/16 mi	100	Yes (few airports)	No	Yes (military only)	Yes
IIIA	700	1/8 mi	-	No	No	No	No
IIIB	150	1/16 mi	-	No	No	No	No
IIIC	-	-	-	No	No	No	No

No System today is authorized for Cat III.

5.2 The Mechanics of Landing

A general understanding of the mechanics of landing is critical to realizing why a landing aid may or may not be capable of guiding aircraft in low-visibility conditions. Generally speaking, an aircraft transitions from an initial approach condition using perhaps VOR/DME or approach control radar (ACR) fixes, to a final approach ILS or precision approach radar (PAR) fixing system at 8-15 miles from the runway. The aircraft continues inbound to the runway at the minimum enroute altitude for the particular terminal maneuvering area (TMA) say (1000-1500 ft approx.) until a glide slope or start descent point is encountered where a controlled rate of descent (glide-slope follow) is commenced. This condition is maintained until either the minimum altitude (based on category and local terrain) is encountered or the runway is sighted.

At present Cat I limitations, the aircraft has sufficient time to level out at the minimum altitude and continue in-bound attempting to gain visual contact with the runway, before going into a landing phase. If no visual contact is gained, a missed approach procedure must be initiated.

If lower categories of visibility are to be used, the aircraft will be required to transition into a landing phase of operation prior to encountering the specified minimum altitude. The landing phase requires several precise operations on the part of the pilot/aircraft system. Consider an aircraft descending with a sink rate of 480-900 ft/min, an airspeed of 130 kts (typical jet transport aircraft), 600 ft above runway*, 2 miles from the touch down point, possibly in a "crab" due to wind and not exactly on the centerline extension due to inaccuracies in the approach/landing system. This situation progresses assuming no runway alignment side-step is necessary, until approximately 75 ft altitude* and 500 ft from the threshold the "flare decision" is made. At 50 ft altitude*, and over the threshold, the flare is initiated. The flare continues until landing some 2000 ft along the runway. During flare the sink rate is reduced parabolically to approximately 2/ft/sec, airspeed is reduced to approximately 105 kts. touchdown speed and at 20 ft altitude* the decrab maneuver is executed. If during an IFR landing of this type the aircraft encounters the minimum altitude restriction, based on visibility category criteria and terrain, without visually sighting the runway, the pilot is required to abandon the landing and execute a missed approach.

---

* Defined as the altitude between the extended landing gear and the runway, typically measured by the altimeter system in the aircraft, calibrated as zero when the aircraft is on the runway, gear down.

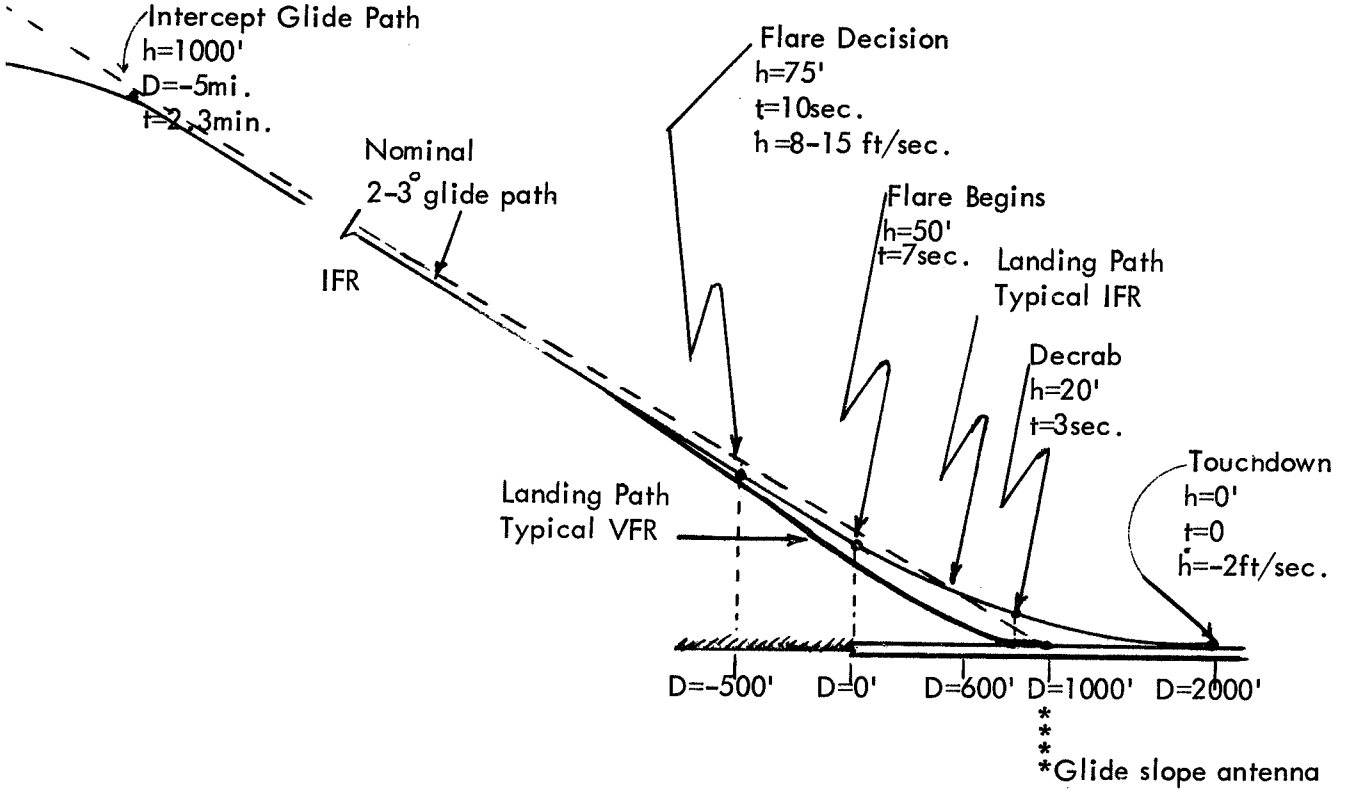

Figure II-7. Typical IFR and VFR Landing Paths.

Note. . . All measurements are approximate.

The foregoing discussion represents a generalized picture of the landing envelope. Aircraft performance and optimal approach requirements vary considerably over this envelope. But, any system capable of operation down to Cat III conditions must be able to interface with the pilot/aircraft to the extent of facilitating the flare, decrab and overshoot decisions. In addition, system accuracy along the runway extension must minimize side-step maneuvers at low and unsafe altitudes. An additional capability for complying with missed approach procedures and accuracy requirements must be provided.

5.3 Characteristics of Instrument Landing Systems

The performance of present ILS systems is summarized in the following paragraphs. The data presented has been extracted from (Ref.19). Since (Ref.19) states system performance in a non-standard format, the approach outlined in (Ref.18) has been followed, i.e., performance requirements have been stated at the 3 σ probability level.

5.3.1 General Description (ILS). - The standard instrument landing system (ILS) consists of a glide-slope beam for vertical steering, a localizer beam for lateral guidance and two or three marker beacons to provide positional (distance from the end of runway) checks. Figure II-8 shows an idealized picture of the two beams and their intersection in relation to the runway.

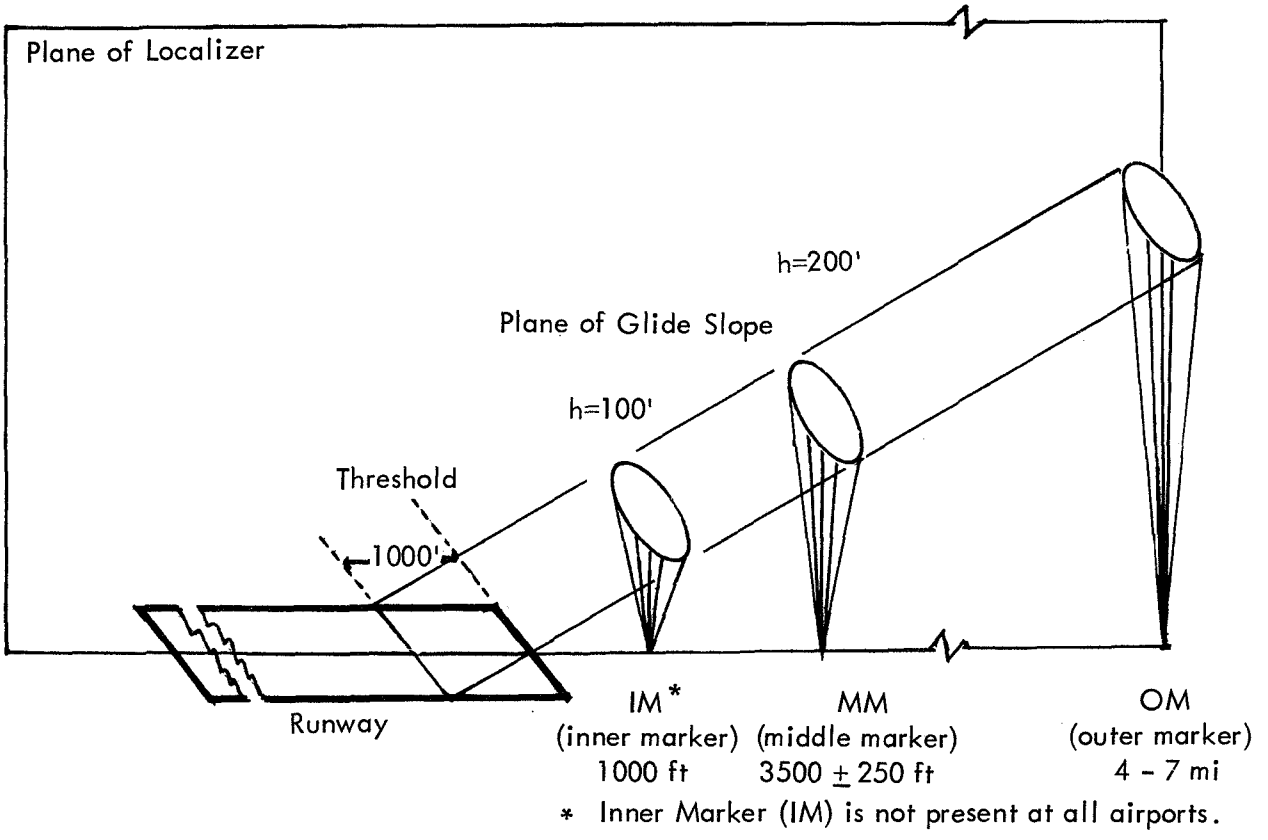

Figure II-8. CAT II Runway Configuration of ILS

The Glide Slope. - Twenty glide slope channels are used in the U.S. separated by 0.3MHz. in the frequency band of 329.3 to 335.0 MHz. Each glide slope channel is paired with a localizer channel so that both receivers can be tuned simultaneously.

Normal acquisition range is 15 nm at approximately 1000 ft. The glide slope carrier is modulated at both 90 and 150 Hz in a pattern such that predominance of the 150 Hz signal causes a fly-up indication to the pilot, the predominance of the 90 Hz signal causes a fly-down indication. The glide slope signal path is linear, while the nominal aircraft glide path is a hyperbola whose asymptote flares out near the runway, never touching the ground. (15 to 30 ft above runway, near the antenna) Therefore, the glide slope cannot be used as a "touchdown" guidance aid.

The glide slope transmissions are subject to multipath effects because of reflections to the aircraft from surface irregularities and nearby objects. This causes apparent bending and distortion of the nominal glide path signal.

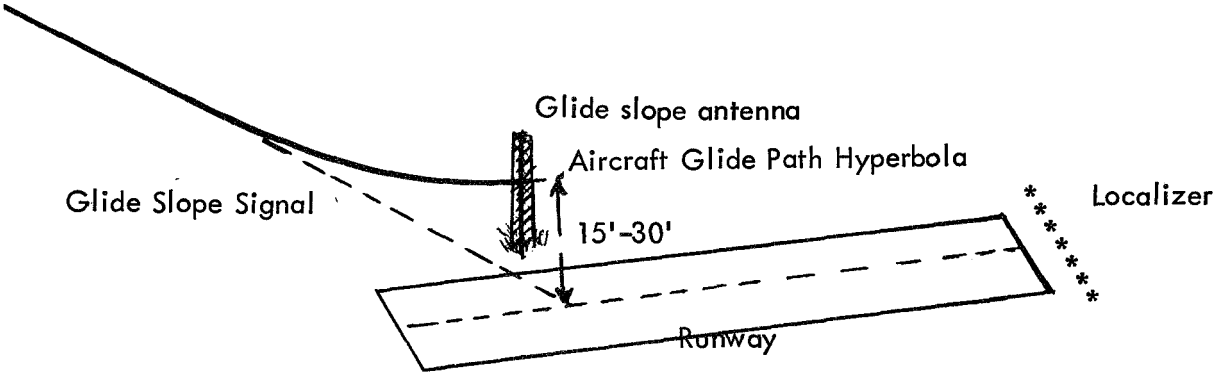

Figure II-9. Optimal Glide Path and ILS Glide Slope.

To achieve Cat II the glide path must be free of these distortions down to 50 ft. Airport sites not having flat runway approach areas must use special, higher-cost, antenna arrays to fulfill Cat II requirements.

The Localizer. - Twenty localizer channels with 0.2 MHz separation from 108.1 to 111.9 MHz, are paired with a glide slope channel. The localizer is aligned with the projected runway centerline and again the carrier is modulated at 90 and 150 Hz. Predomination of the 90 Hz modulation generates a "fly-right" indication to the pilot and conversely a "fly-left" indication occurs when the 150 Hz modulation is predominant. The localizer antenna is located several hundred feet beyond the "stop" end of the runway.

Again, multipath effects cause apparent bending or scalloping in the localizer pattern. These irregularities may be reduced by special, albeit higher cost, two array configurations.

Marker Beacons. - The 75 MHz marker beacons are used as spot distance checks from the runway and have the following configurations.

(a) Outer Marker - (OM) - 4-7 miles from threshold (generally 4.5 miles)
- 400 Hz modulation, 2 dashes/sec. audio
- lights purple light in pilot's panel
- glide slope interception point.

(b) Middle Marker - (MM) - glide slope 200 ft above runway
- approx. 3500 ft from threshold
- 1300 Hz modulation
- dash dot audio presentation
- lights amber light on pilot's panel
- Cat I decision point.

(c) Inner Marker - (IM) - Required only at Certified Cat II airports
- glide slope 100 ft above runway
- approx. 1000 ft from threshold
- 3000 Hz modulations
- 6 dots/sec. audio
- light white light on pilot's panel
- Cat II decision point.

5.3.2 General Performance Requirements. - The frame of reference for the landing approach path which has been adopted by ICAO is shown in Figures (II-10&11). It is to be observed that this specification is anchored to threshold ILS reference point and developed in reverse sequence from there. ILS system performance requirements are referred to this diagram. The standard refers only to the last four miles of the approach. A flat overrun of 200' is specified, however, more recent documents (Ref.16) contain a terrain model which illustrates the degree of variation which can be expected during the last mile.

As discussed previously, the basic requirements for an ILS system comprise:

VHF glide path and localizer equipment, associated monitor system and indicator equipment.

. VHF marker beacons, monitors, remote control and indicator equipment.

There are other requirements related to the location of control points, monitoring standards, frequency interlock, etc., which while of interest generally do not affect the performance criteria which are relevant to this study.

- Localizer and Associated Performance Requirements

The performance of the ILS Localizer equipment is specified in terms of coverage and guidance accuracy for the three categories of operation.

The coverage requirements for the localizer state that coverage shall extend from the center of the antenna system to distances of:

25 nautical miles within $\pm$ 10° of the front course.

17 nautical miles between 10° and 35° from the front course line.

10 nautical miles outside of $\pm$ 35°.

If alternative navigation facilities are available, the coverage requirement may be reduced to 18° instead of 35°. The signals must be received at the distances specified and above a height of 2000' above the threshold or 1000' above the elevation of the highest point.

Localizer Course widths at threshold and ICAO Point B are shown in Figure II-11. The widths shown define the point at which maximum deviation of the localizer needle occurs. Localizer angular sensitivity is varied for long and short runways to achieve the $\pm$ 350' course width at threshold.

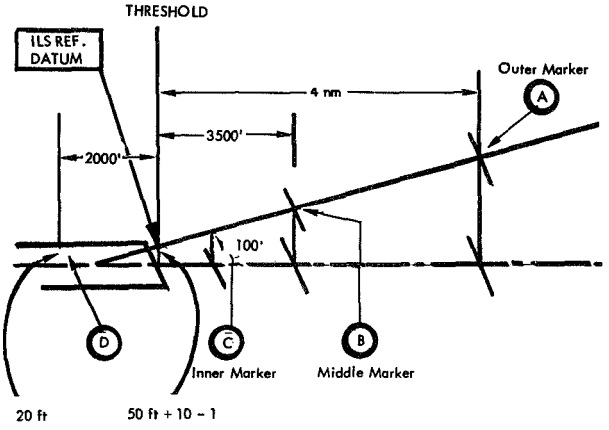

Figure II-10. ICAO/ILS Reference Points

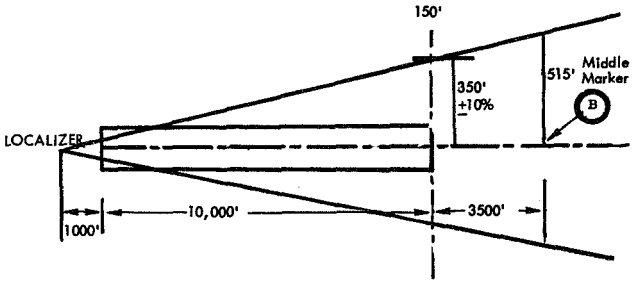

Figure II-11. ICAO/ILS Localized Course Width at Threshold and Point B

Accuracy requirements for ILS localizer are shown in Table II-20. The ICAO standards have been stated at the 3σ level. Note that, excluding flight errors, worst case errors are 84 ft, 93 ft and 111 ft at threshold points C & B respectively. RSS errors at the same points are 50 ft, 56 ft and 66 ft respectively. It is significant to note that total ground equipment error contribution is of the same order of magnitude as airborne equipment.

- Glide Slope Performance Requirements

The glide slope provides a straight line descent path in the vertical plane containing the center line of the runway. θ is the angle used to denote the nominal path angle. It

is a recommendation that this angle be made variable from 2 to 4 degrees. The operationally preferred glide path angle is 2.5 degrees for Class III aircraft. An angle in excess of 3° is to be used only if obstruction clearance demands it.

The glide path angle shall be adjusted and maintained within:

- 0.075 θ for Cat I & II
- 0.04 θ for Cat III

The ILS reference datum shall be:

- 50' ± 10' for Cat I
- 50' + 10' - 0' for Cat II and III

TABLE II-20. CAT II - LOCALIZER PERFORMANCE

Parameter	ICAO Ref.	ICAO Cat. II Amount	3σ Value at threshold	3σ Value at Point C	3σ Value at Point B
Sector width with 10%	3.1.1	700' ± 70'	750' ±20'	775' ±75'	935' ±95'
Centerline Monitor	3.1.4.5.4	±25 ft threshold ±15' recommended	25 ft.	28 ft.	33 ft.
Course Bends	2.1.4	±5 microamps (2σ)	20 ft.	22ft.	26 ft.
Receiver Centering (airborne)	2.2.4.1	±5 microamps (1 σ)	39 ft.	43 ft.	52 ft.
All flight errors FAA/AC 120-20 (crab angle wind shear. normal tracking poor heading)		±25 microamps or 1/6 full scale (1σ level)	97 ft.	104 ft.	127 ft.

TABLE II-21. ILS LOCALIZER PERFORMANCE REQUIREMENTS FOR CAT I, CAT II & CAT III AT POINT B (ft)

	Cat I	Cat II	Cat III
Alignment	35	33	10
Coursebends	127.5	26	25
Receiver Centering	72	52	-
Worst Case Error	234	111	35
RSS	± 150	± 66.8	± 27

The 3 σ values of the 100' point are given in Table II-22.

TABLE II-22. 3σ VALUES OF THE 100-FT. POINT

Error	ICAO Ref.	ICAO Spec.	3σ
Course Shift	3.1.4.6.1	0.2°	8'
Beam Bends	2.1.5	$20\mu\alpha$ at 2σ	5'
Receiver Centering	2.2.5.1	$27\mu\alpha$	5'
Linearity Flight Error	3.1.4.5.4.7	(20%)	12'

The variation in glide path angle and path height over threshold for Cat II is shown in Figure II-12.

The variation in Point C (the 100' height point) with glide slope errors is shown in Figure II-13 for a nominal 2.5° glide slope. It is to be observed that at the 3 σ level the distance to the 100' altitude point is from 740' to 1660'.

Glide path errors over typical thresholds added to ICAO variation in path height are shown in Figure II-14.

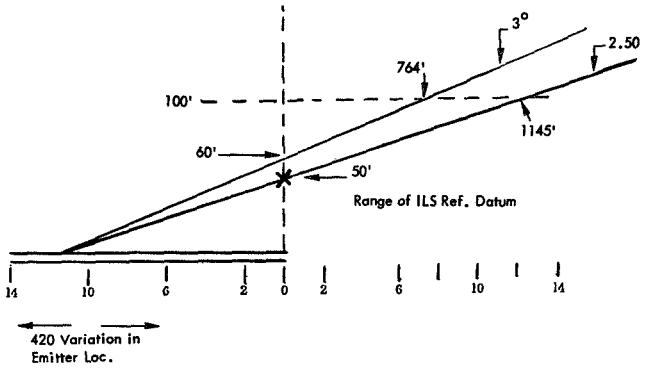

Figure II-12.
Variation in Glide Path Angle and Path Height for Cat II and Cat III

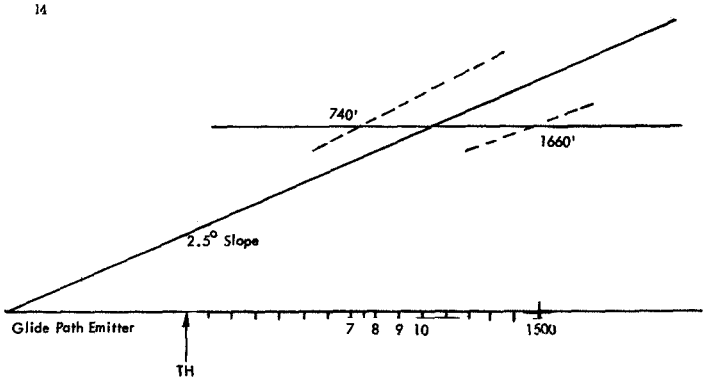

Figure II-13.
Variation in Point C with Glide Slope Errors

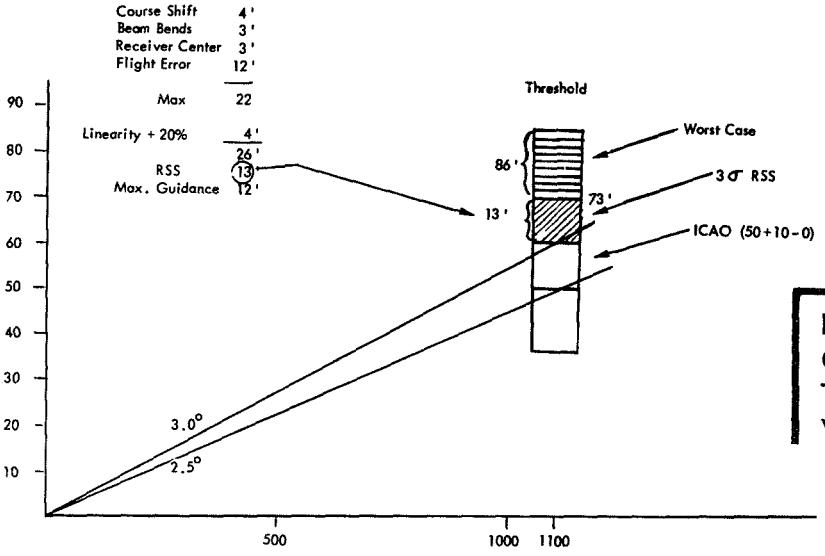

Figure II-14.
Glide Path Errors Over Typical Thresholds Added to ICAO Variation in Path Height

- Combined Performance Requirements

The lateral and vertical performance tolerances (including Piloting Error) are combined and shown in Figure

The 3σerror window is:

280' by 90' at Point B

235' by 50' at Point C

- Other Performance Requirements

Other performance requirements relate to the location of marker beacons, equipment siting, monitoring of system performance and identification. These are summarized below. They are included only to indicate the type of performance and functions which are currently provided in the existing ILS. Further detailed system analysis is required to define a compatible set of functions in this detail for an IALM System.

. Marker Beacons

Two marker beacons must be provided in each system, (a third beacon may be added if necessary). The beacons shall indicate predetermined distance from the threshold along the ILS glide path. The beacons shall provide visual indications for 3 seconds (± 1 sec.), 6 seconds (± 2 secs.) and 12 seconds (± 4 secs.) at the inner, middle and outer markers. Each marker carries identification data in the form of 6 dots per second, alternate dots and dashes and dashes (2/second) for inner, middle and outer markers respectively.

It is recommended that the inner marker be from 1000 to 1500 ft, the middle marker at 3500 ± 500 ft and the outer marker 3.9 nautical miles from the threshold. The markers shall be within 100 ft, for the inner marker and 250' for the middle and outer markers, from the extended centerline of the runway.

. Equipment Siting

Localizer equipment shall be located on the extension of the centerline of the runway at the stop end. The glide path antenna should not be less than 400' from the runway centerline.

. Monitoring

An automatic monitoring system shall be provided for the localizer which provides warnings when:

a) Radiation ceases.

b) Navigation and Identification data is removed from the carrier.

c) The facility reverts to lower category performance.

These warnings will be provided when:

a) For Cat I Localizers, the mean course line deviates more than 35' at the ILS reference datum.

b) For Cat II, when course line deviates more than 25'.

c) For Cat III, when mean course shifts more than 20'.

d) A reduction of power to less than 50% for single frequency systems occurs.

e) A reduction of power to less than 80% for two frequency systems occurs.

f) A change of displacement sensitivity of more than 17%.

The glide slope monitoring system shall provide warnings when:

a) Mean glide slope angle shifts more than 0.025 θ.

b) When power drops to less than 50% or 80% as in the case of the Localizer.

c) When accuracy drops below that required for Cat I, II or III performance.

These warnings are utilized only in the control centers at present and automatic transmission of the data should be considered.

5.3.3 ILS Installations. - On a world-wide basis there are 500 ILS installations, of these, half are within the continental United States. A typical installation will have one system of glide-slope, localizer and beacons oriented to the main runway. However, major airports do have several installations oriented to various runways. Most ILS installations are authorized for use within Cat I conditions but not all of them are authorized to the minima for Cat I. Several installations have Cat II authorization. (See Table II-23). Within the near future, a total of 23 Cat II installations will be authorized.

5.3.4 Future Systems. - "The Radio Technical Commission for Aeronautics (RTCA), believing that it is timely to consider a successor system to the ILS, has established Special Committee 117. This committee is composed of expert operational and technical representatives from both government and industry. Its objective is to develop a precision guidance system concept for approach and landing and an associated signal structure. The concept and signal structure should satisfy, to the maximum extent possible, the various operational needs of the several classes of users. The committee is striving to achieve a continuing dialogue between the people who define operational needs, and the scientists and engineers who strive to meet those needs."

The above paragraph is excerpted from an RTCA Paper (Ref. 16). While no formal development decision has been made concerning the so-called "ILS replacement", a considerable amount of constructive and progressive work has already been generated

by RTCA SC-117. Of particular importance to this study, at the time of this writing are two subjects. First, a recommendation has been made by SC-117 to concentrate its further efforts on a scanning beam ground based approach and landing system. It is too early in the development cycle to discuss in detail in this report any of the competing proposed system concepts, other than to identify that the scanning beam technique was selected from a series of proposals which included multilateration or hyperbolic concepts as the main alternative category.

For the purposes of this study, the second subject, that of the technical performance requirements set down by SC-117, were considered important enough to be included. In this way, the initial requirements that are being used as design criteria can be viewed in the light of the airborne ILM solution.

TABLE II-23. INSTALLATIONS AUTHORIZED CAT. II MINIMA FOR ILS AS OF 8 DECEMBER 1969

City	Runway	Minima
Atlanta	9R	1600 RVR Day-1200 RVR Night
Chicago, O'Hare	14L	1200 RVR Day-Night
Chicago, O'Hare	14R	1200 RVR Day/Night
Dulles	1R	1600 RVR Day-1200 RVR Night
Denver	35	1600 RVR Day-1200 RVR Night
Detroit	3L	1600 RVR Day/Night
Houston	8	1200 RVR Day/Night
Milwaukee	1	1600 RVR Day/Night
Minneapolis	29L	1200 RVR Day/Night
New Orleans	10	1600 RVR Day-1200 RVR Night
Washington National	36	1600 RVR Day/Night

Note: FAA long range plans call for the installation of Cat. IIIA ILS at 24 locations in the 1970-1080 time period.

. Tentative Technical Requirements - RTCA SC-117

The following Table II-24 contains the minimum performance values for a initially defined series of operational configurations which were considered by SC-117.

TABLE II-24. MINIMUM PERFORMANCE VALUES FOR OPERATIONAL CONFIGURATIONS (Notes: 1/ 8/)

GUIDANCE CHARACTERISTICS	Config. B	Config. D	Config. E	Config. F	Config. G	Config. I	Config. K
2/ Bias:	50' or 0.25°	50' or 0.25°	50' or 0.25°	32' or 0.18°	32' or 0.18°	10' or 0.072°	10' or 0.072°
3/ Noise:	26' or 0.133°	26' or 0.133°	26' or 0.133°	11' or 0.066°	11' or 0.066°	9' or 0.066°	9' or 0.066°
2/ Bias:	N/A	6' or 0.1°	6' or 0.1°	1.2' or 0.1°	1.2' or 0.1°	1.2' or 0.1°	1.2' or 0.1°
3/ Noise:	N/A	7' or 0.117°	7' or 0.117°	1.4' or 0.07°	1.4' or 0.07°	1.4' or 0.07°	1.4' or 0.07°
2/ Bias:	300'	300'	100'	100'	20'	20'	20'
3/ Noise:	6/	6/	6/	6/	6/	6/	6/
Dev. Course Width 4/ AZ	± 350' at Threshold	± 350' at Threshold	± 350' at Threshold	± 350' at Threshold	± 350' at Threshold	Air 5/ Selectable	Air 5/ Selectable
EL	N/A	± .240 x θ	± .240 x θ	± .240 x θ	± .240 x θ	Air 5/ Selectable	Air 5/ Selectable
Data Rate	2 Hz	4 Hz	4 Hz	5 Hz	5 Hz	5 Hz	5 Hz
System Capacity	15 acft	15 acft	15 acft	50 acft	50 acft	50 acft	50 acft
9/ Channelization	40 Channels	40 Channels	40 Channels	40 Channels	40 Channels	40 Channels	40 Channels
COVERAGE	Config. B	Config. D	Config. E	Config. F	Config. G	Config. I	Config. K
(Vertical Guidance) Horz.	N/A	± 20°	± 20°	± 20°	± 20°	± 40°	± 90°
Vert.	N/A	1° - 8°	1° - 20°	1° - 8°	1° - 20°	1° - 20°	1° - 20°
Range	N/A	20 nm	20 nm	20 nm	20 nm	20 nm	20 nm
(Lateral Guidance) Horz.	± 20°	± 20°	± 20°	± 20°	± 20°	± 40°	± 90°
Vert.	1° - 5°	1° - 8°	1° - 20°	1° - 8°	1° - 20°	0° to 20° 7/	0° to 20° 7/
Range	20 nm	20 nm	20 nm	20 nm	20 nm	Stop End To 20 nm	Stop End To 20 nm
DME Horz.	± 20°	± 20°	± 20°	± 20°	± 20°	± 40°	± 90°
Vert.	1° - 5°	1° - 8°	1° - 20°	1° - 8°	1° - 20°	0° to 20° 7/	0° to 20° 7/
Range	20 nm	20 nm	20 nm	20 nm	20 nm	Stop End To 20 nm	Stop End To 20 nm
PATH LOCATION							
Vert.	N/A	Fixed 2° - 6°	2° - 15° Air Select.	Fixed 2° - 6°	2° - 15° Air Select.	2° - 15° Air Select.	2° - 15° Air Select.
AZ	Extended Centerline					Air Select. ± 40°	Air Select. ± 90°

NOTES: 1/ These are net values which include both airborne and ground components of system.

2/ Bias refers to tolerable error of mean (±).

3/ Noise includes spatial, temporal and resolution perturbations.

4/ Accuracy values are specified for the minimum height designated in respective configuration descriptions. Angular values for elevation accuracies use origin at touchdown zone. Azimuth accuracies and course widths are specified with respect to stop end of the runway and use of the following runway lengths as arbitrary references: (1) B,D, and E -- 7,000'; (2) F and G -- 12,000'; (3) I and K -- 14,000'.

5/ Elevation and azimuth course widths are dependent on aircraft type and selected angle θ.

6/ Compatible with a tolerable range rate error; e.g., 10 feet per second. Integration time should be specified.

7/ The angle 0° applies to at least the length of the runway plus 0.5 mile beyond the approach end of the runway.

8/ Additional technical narrative guidance under the following headings is attached hereto:

1. Station Identification.
2. Obstacle Warning.
3. Monitor and Flag Alarms.
4. Missed Approach Guidance.
5. Installation Factors.
6. Co-location with Existing Facilities.
7. Electromagnetic Compatibility (EMC).

9/ If the total system service requires more than one rf frequency, automatic pairing shall be provided.

1. Station Identification. Four sequentially ordered alphabetic characters to identify geographic location, and two numeric characters designating the serviced runway, shall be transmitted as modulations of the guidance signals. In addition, at least four distinct indications of status of the guidance facility shall be provided. These identification and status messages shall be repeated at least every ten seconds, and shall produce aural Morse code or voice outputs from the air-borne equipment. Capability for the automatic recovery and static visual display of the message data is desirable as a supplement to the aural outputs. Capability to transmit "canned messages" which are related to the landing procedure also is desired.

2. Obstacle Warning. An obstacle warning which defines the minimum safe gradient in approach and missed approach areas is desired.

3. Monitors and Flag Alarms. Ground-based monitors shall be provided which automatically detect and respond to significant degradation or loss of any transmitted guidance signal. Monitor tolerances and adjustability shall insure compliance with system accuracy specifications and with any safety criteria peculiar to each installation. Airborne flag alarm signals shall be provided which respond to signal losses from any cause, to unreliably weak signals, and to inconsistencies in signal format tending to result in false data. Separate alarm signals shall be available for azimuth, elevation and distance data. Flag alarm response times shall not exceed one second.

4. Missed Approach Guidance. Lateral guidance shall be continued over the length of the runway and at least 5 nm from departure end into the takeoff/overrun zone. Vertical coverage of the lateral guidance shall extend from the base altitude to at least 2000 feet altitude throughout this region. All other characteristics of missed approach lateral guidance shall duplicate those applicable to approach guidance, except that accuracy shall be ± 160 feet (2σ), over and in the immediate vicinity of the runway. Vertical guidance in the missed approach zone is desirable.

5. Installation Factors. The locations of surface guidance facilities relative to each other and to the landing zone shall be sufficiently flexible to avoid conflicts with existing surface features such as taxiways and structures. Manual adjustments to the airborne equipment in compensation for such variations in installation geometry shall not be permissible.

6. Co-location with Existing Facilities. The instrument landing system provided shall be designed such that its normal performance characteristics fall within prescribed tolerances when co-located with an existing conventional instrument landing system. Co-location shall be interpreted as being physically located so as to serve the same runway with azimuth, elevation and distance guidance, and with no degradation in performance characteristics of the existing system.

7. Electromagnetic Compatibility (EMC). The system and its equipment elements shall neither produce nor be vulnerable to radio interference to such a degree that standard electromagnetic control methods would be ineffective. Misleading indications due to accidental interference shall be prevented. Positive safeguards against hostile jamming are desirable options for military applications.

5.4 VOR/DME as an Approach Aid

Generally speaking, VOR/DME is not used to any great extent as a final approach aid today. This is due, in part, to the fact that the vast majority of airports serving air carrier aircraft are now equipped with some form of Instrument Landing System.

However, if we consider a hypothetical case at an airport which does use VOR/DME as a landing approach aid, we are better able to understand the reluctance of air carriers and airports to rely on this method. Assuming a jet-powered aircraft (see Fig. II-15) on an approach path to an airport runway with a speed of approximately 130 knots, the minimum time lapse allowable between breaking below the 200 ft decision height of Cat I and touchdown is approximately 19 seconds. This means that the start of descent to the runway must occur when the aircraft is approximately over a point 0.69 nautical miles from touchdown.

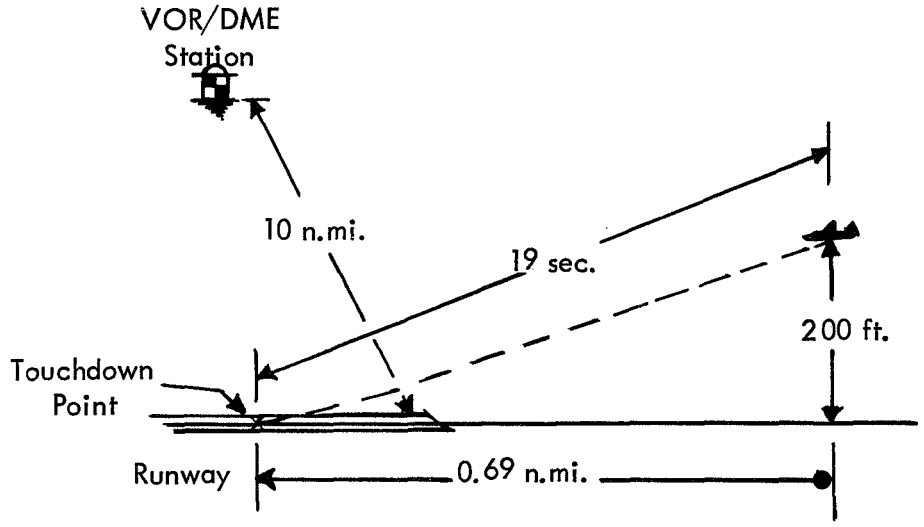

Figure II-15. VOR/DME Landing Approach

Further assuming a VOR/DME station 10 miles from the airport, and using the following figures which represent the generally accepted minimum errors for VOR/DME then the absolute minimum visibility must be the sum of the minimum let down distance and the largest VOR/DME error.

1. The ground based equipment at the station has an inherent error of 1.1° for standard VOR, and 0.5° for precision VOR (PVOR); and a DME error of 0.2 naut. mi. for standard and 0.1 n. mi. for precision equipment.

   Note: Due to the greater magnitude of VOR error, at 10 miles the DME error is insignificant.

2. The airborne equipment has an inherent error of 2° for standard VOR, or 1° if the equipment is extremely well-maintained, and 0.5° for PVOR.

TABLE II-25. VOR/DME APPROACH ERRORS

Case	VOR Ground Equip Error	Aircraft Equipt. Error	Aggregate Error	Maximum Perpendicular Error at 10 N.Mi.	Maximum Total Distance From Touchdown
A	1.1°	2.0°	2.28°	0.38 n. mi.	1.07 n. mi.
B	1.1°	1.0°	1.48°	0.24 n. mi.	0.93 n.mi.
C	0.5°	0.5°	0.7°	0.12 n. mi.	0.81 n.mi.

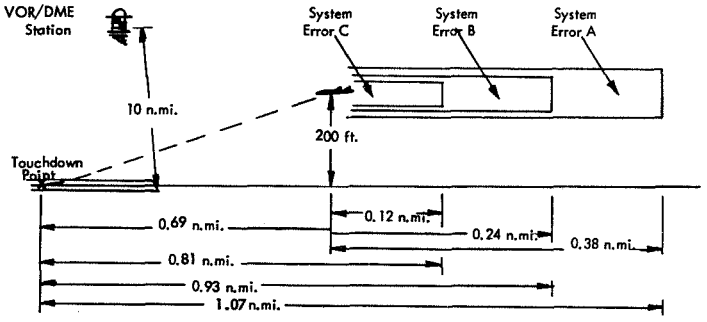

Figure II-16. VOR/DME Approach Errors

The total distances involved for Cases A, B, and C do not take into consideration such factors as flight technical error or pilot induced errors. With these in mind it is readily apparent that none of the VOR/DME candidates can provide a Cat I capability.

Under present FAA regulations, VOR/DME minima are on the average 800 and 1 (i.e., 800 ft above terrain and 1 mile meteorological visibility).

5.5 GCA or PAR

"Ground-controlled approach" (GCA) and "precision approach radar", (PAR) are the respective military and civil names for an X-band, ground-based radar landing system that tracks and guides landing aircraft. Steering corrections are transmitted to the pilot via a standard radio voice link. Consequently, no specialized equipment need be carried by the aircraft.

The system consists of two scanning beams. The vertical plane beam is 1.5° high by 0.6° wide and scans a 20° sector in azimuth, centered on the extended runway center line. The horizontal plane beam is 0.4° high by 3° wide and scans a 7° vertical sector centered on the glide-slope, 2.5° to 3° above the horizontal plane. Each beam makes four scans per second and shows the aircraft's path on two cathode-ray-tube screens, superimposed on a drawing of the ideal glide path. The range accuracy is 200 ft $\pm$ 2 percent of range (Ref. 20).

Military GCA systems and operations were authorized to land aircraft in the equivalent of civilian Cat II conditions in 1968. However, GCA/PAR is generally used as a low approach and ILS monitoring system. Overall accuracy and safety is dependent on the alertness and skill of both the pilot and operator.

GCA/PAR has long been recognized to have several weaknesses:

The deficiencies of the GCA included poor closed-loop response, weak signals reflected from the aircraft, obscuration of the reflected signals by weather, and ground "clutter" of the (ground) controller's scope. The cost of having a trained GCA team always available 24 hr. a day, 365 days a year --- also posed a serious deterrent (Ref. 21).

Compiled with these are the modern day problems associated with large jet aircraft (difficult to establish center of aircraft on scope) and heavy traffic flow (GCA/PAR have low system capacity).

5.6 Automatic Landing Systems

Over the past few years several airborne systems have been developed to augment ILS and provide landing guidance in the region from 100 ft altitude downward to the runway.

5.6.1 BLEU Automatic Landing System. - One such system developed by the British Government research agency at the Royal Aircraft Establishment, Blind Landing Experimental Unit was the BLEU system. This system utilizes a combination of ILS, radio altimeter, flare computer and magnetic leader cable. The leader cable system is composed of two cables laid parallel to the runway centerline and extending 5000 feet into the undershoot area and 500-1000 feet past the glide slope antenna. As long as the cables are symetrically installed about the centerline and both supplied with a constant current, then the plane of the centerline is defined by equality of the magnetic fields.

The BLEU system although demonstrably accurate has two economic limitations, the right-of-way requirements in front of the threshold and excessive aircraft receiver weights.

5.6.2 Auto Land. - Another British system is the "Auto Land" developed by SUD-Lear. To some extent a spinoff from BLEU, the Auto Land system came about as a result of improvements in ILS beam stability. The basis of the system is, of course, the more stable ILS beam and the autopilot coupling, but in addition, the system requires a radar altimeter and vertical programming, an open loop glide slope, a flare computer, augmented flight controls and an auto-throttle to provide pitch, speed and descent control.

The Auto Land system has undergone considerable flight testing. Results of 20 landings made at Toulouse (poor ILS glide path) were as follows (Ref. 22).

- between 400 ft and 50 ft all aircraft trajectories were determined to be within $\pm 0.1^{\circ}$ from centerline of mean descent path defined by glide beam.

  50% of the landings were inside a 55 meter along-runway zone, and all were within a 128 meter zone (center 608 meters from threshold).

  vertical speed at touchdown was between 0.63 and 2 ft/sec.

5.6.3 Other Systems. - Several automatic landing systems using ILS have been developed in the United States. These are (Ref. 23).

Precision Approach and Landing System (PALS)
Boeing Co. & Bendix Corp. primarily for Boeing 707/720.

Automatic Flight Control System (AFCS)
Douglas Aircraft Co. & Sperry Phoenix Co. primarily for DC-8.

All Weather Landing System (AWLS)
Lockheed-Georgia Co. primarily
for USAF on C141.

5.7 All Weather Landing System Concepts

In the U.K. the current thought is for the pilot to act in a command and monitor role, with the necessity of a pilot takeover hopefully eliminated by reliable automatic systems. In effect then the pilot remains outside of the control loop.

In the U.S. however, the focus is to keep the pilot within the control loop. One concept developed is to use electronic force sensors on the controls and have these inputs added to the automatic control inputs. Therefore, if the pilot wishes to take over, he may also do so by performing his normal maneuvers.

Again, because of economic factors, development has followed along the lines of utilizing improved ILS as the basic input. Although these systems are apparently capable of full automatic landings, commercial aircraft are today only certified to Cat II landings at approved airfields.

5.8 Summary of Approach and Landing Aids

The following limitations exist with today's approach and landing aids. At best these limitations can restrict full utilization of airports in Cat III visibility conditions.

5.8.1 ILS. - ILS, theoretically, can be developed to sufficient accuracy in the localizer and glide slope planes, to be used for Cat III landings. Unfortunately, it is still subject to local distortion, bends, scalloping, etc. Range to touchdown information is presented neither accurately nor adequately to the pilot.

Present ILS systems are limited in the number of aircraft they can handle at a given time and only give a general not optimal approach path to the aircraft. Advanced ILS configurations may appear technically feasible but their economic cost benefit has yet to be determined.

5.8.2 VOR/DME. - Today, VOR/DME is not authorized for use in Cat I conditions. Such developments as PVOR (precision VOR) when used with specialized aircraft equipment are capable of the accuracies required for Cat I and perhaps Cat II landings.

5.8.3 GCA/PAR. - Ground controlled approach presently is not authorized for civilian use below Cat I although it has been demonstrated within the military to be capable of Cat II landings. Accuracy improvements are possible, however, the inherent high costs of equipment and 24 hour GCA teams preclude the utilization of GCA/PAR for Cat III. The restricted utilization rate of GCA/PAR is also a critical factor at large, high density airports.

5.8.4 Automatic Landing Systems. - Various automatic landing systems, although not authorized, have demonstrated Cat III landing capability. The weak link in the automatic landing system chain is the in-bound guidance beam. A system utilizing ILS beam guidance is limited by the vagaries and distortions of ILS at various airports. Although automatic landing systems may be the answer, this single ILS ground to air link is particularly subject to errors and non-standardization of approach. Current ILS systems do not provide for redundancy, or back-up capability, nor do they provide for the steeper descent angles which are characteristic of VSTOL aircraft.

5.9 Conclusion

In conclusion then, it can be seen that a requirement exists for a highly accurate, airborne landing system, which can be used either in a primary or backup role to provide landing information. Such a system would, when coupled with existing systems, give safe, redundant in-bound tracking information; provide standardization of approach at various airports; allow higher utilization of airports; and permit the aircraft to fly its optimal approach path.